



# ***HYDROBALLISTICS***

## **Development, Theory & Some Test Results**



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**Sponsor: PMS-210 Through NSWCDD CSS**

# **MH-60S With RAMICS Installed**



**Target Reacquisition Using LIDAR**  
**MK 44 Bushmaster II Chain Gun**  
**MK 258 Hydroballistic Ammo**

# What Is Hydroballistics?

- The Study Or Design Of Objects That Have Momentum Underwater
  - Fully Wetted, Cavitating, & Supercavitating
- Key Parameters Are Drag, Stability & Control, & Structural Integrity
- Water Entry Of Projectile Considerations:
  - Air Entrainment (Not A Great Factor In Supercavitating Bodies)
  - Water Impact Loads

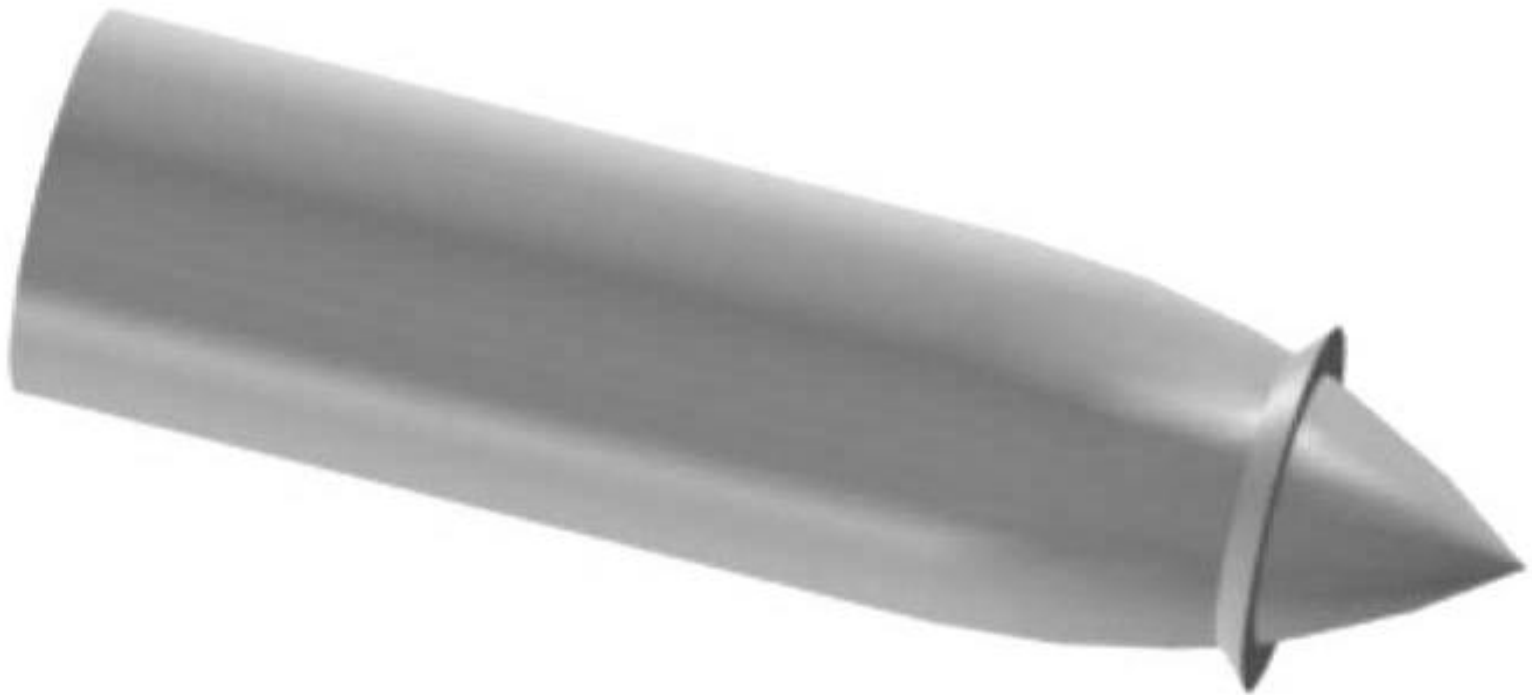
# Hydroballistics Of Supercavitating Water Entry Projectiles

- Spin-Stabilized (In-Air) Projectiles Are Not Good Performers
  - Conventional Bullets Tumble Quickly After Water Entry
- Mass Stabilized Projectiles Are Successful
- High L/D Projectiles Have Consistently Proven Superior Hydroballistic Performance
  - Stabilizing Empennage Shared For Both Air And Water

# History Of Water-Entry & Supercavitation Work

- 1870: Franco-Prussian War - Kopfring Developed
- 1908: “Study Of Splashes” - First Water-Entry Photos (Worthington)
- WW I: Edison Proposed Pagoda Head For Water-Entry Device
- WW II: Torpedoes, Mines, and Water-Entry Bombs
- Post WW II: Numerous Water-Entry/Cavitation Studies Of Rockets & Gun-Launched Projectiles
- 1970’s To Present: Exploit Supercavitation (Drag Reduction)

# Kopfring Device



## **25mm WHITE OAK DEVELOPMENT (1995-1996) ONR Sponsor**

Series I: Adapt Finned Long-Rods (U. S. Army 25mm M919 APFSDS-T); 9 Shots – Blunt Nose Proved Successful With Fins

Series II: Optimize Design (Reduce Nose Flat, Lengthen Nose & Increase Material Strength); 15 Shots

Series III: Introduced Carbide Nose Insert; Last Shot Established Record For Water Vehicles At 4300 ft/sec; 21 Shots

# **Hydroballistic Nose Shapes Tested At White Oak – Series I**



**Blunt Nose**



**Conical Nose**



**Power Law Nose**



# **Refinement Of The Blunt Nose At White Oak – Series II & III**



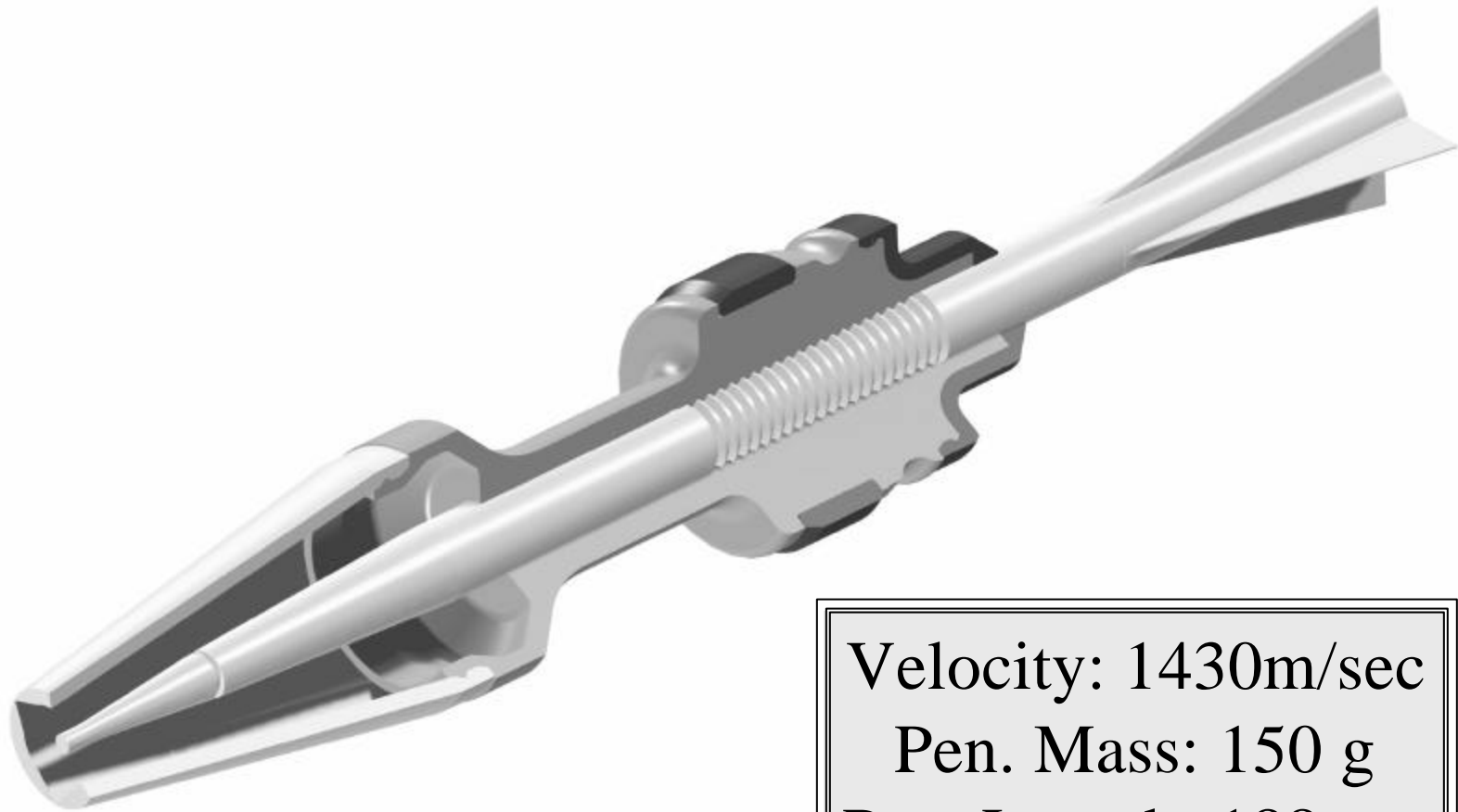
**Generation I**



**Generation II**

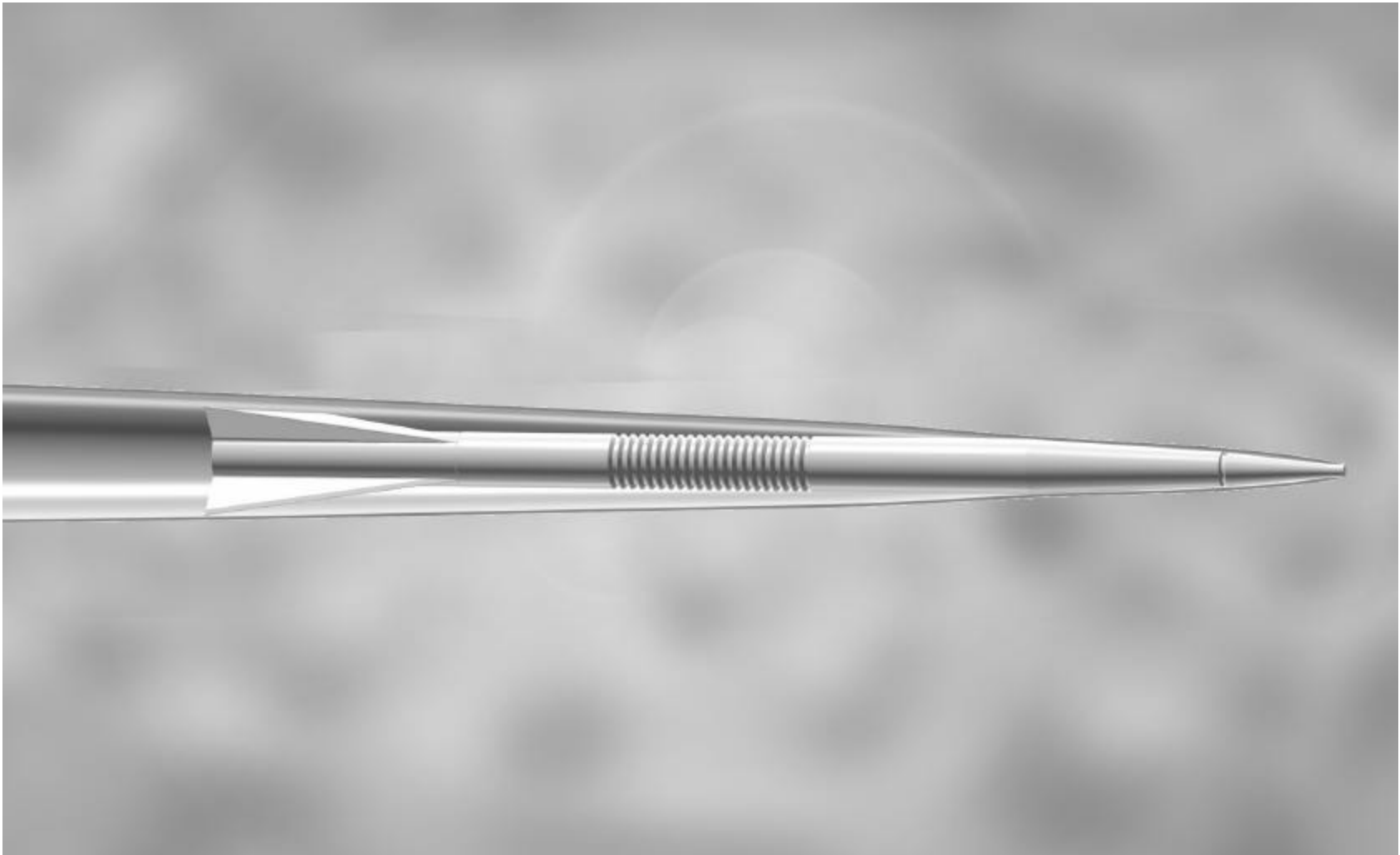


**Generation III  
(Carbide Insert)**



Generation IV:  
MK 258 Mod ?

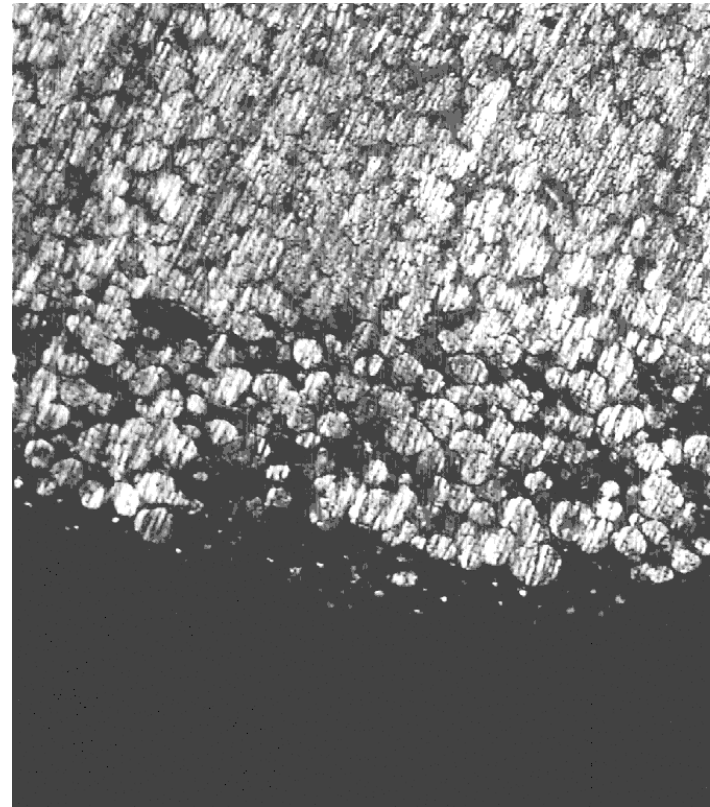
Velocity: 1430m/sec  
Pen. Mass: 150 g  
Pen. Length: 188mm  
Pen. Dia: 9mm  
Nose Dia: 2.3mm



**Cavity Equation:**  $y = \frac{d}{2} \sqrt{(kx/d) + 1}$

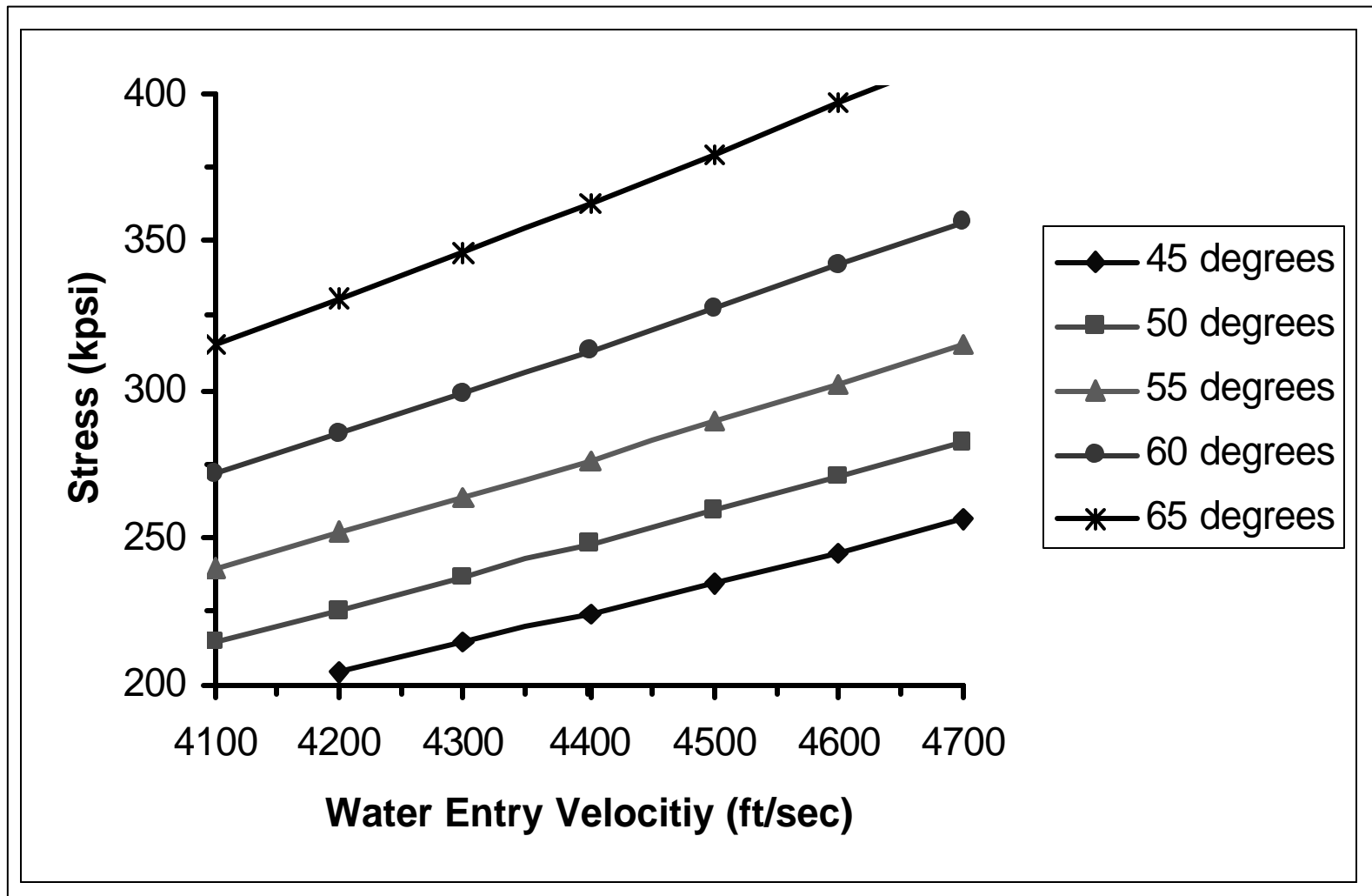
# Water Impact Loads

- Theoretical Formula:
$$C_d^* = 0.79 + 0.93 \tan(\alpha)$$
- Stress At *Preferred* Impact Angle (60°) Can Climb To Over 300,000 psi
- Carbide Tips Successfully Tested (420,000 psi Strength)
- Successful Tests At 45° Exceeded Material Strength
  - Bow Shock May Mitigate Impact Load



Shot #8494: 3800 ft/sec; Mat. Limit – 3700 ft/sec 90x Magnification

# ***Theoretical Water Entry Loads***



# (HYDRO) DRAG COEFFICIENT

- Same Principle As Aerodynamic Drag
- Instrumentation provides:
  - Water Impact Velocity,  $V_0$
  - Trajectory Time,  $T$

$$b = \frac{W}{C_d A}$$

$$T = \frac{2b}{rV_0} e^{\frac{rS}{2b}} - 1$$

$$V = V_0 e^{-\frac{rS}{2b}}$$

**Known**

***W: Weight***

***A: Reference Area***

***S: Length***

**HYDROBALLISTIC TEST SERIES I & II  
ABERDEEN TEST CENTER  
BRIAR POINT TEST POND  
APRIL & AUGUST to OCTOBER 2000**

***OBJECTIVES***

**VERIFY PERFORMANCE OF 25MM**

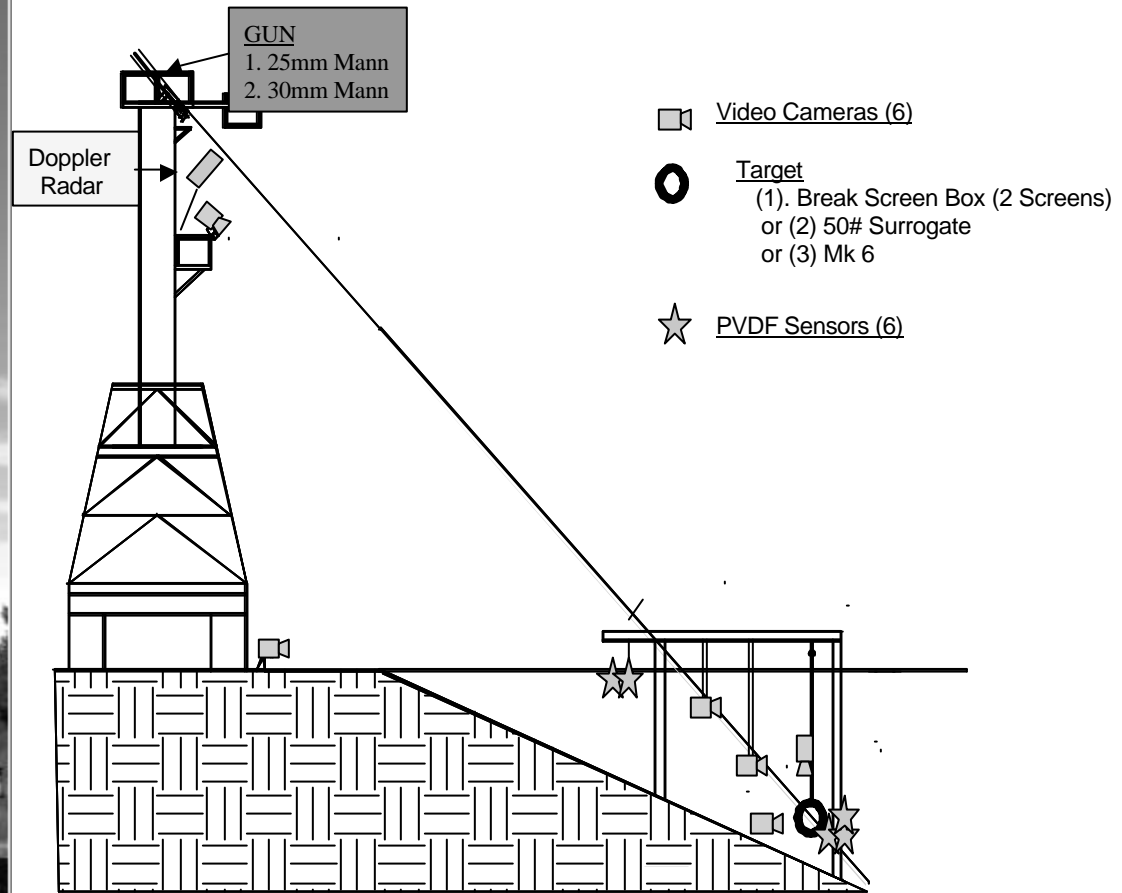
**EVALUATE PERFORMANCE OF 30MM**

**DEMONSTRATE UNDERWATER LETHALITY**

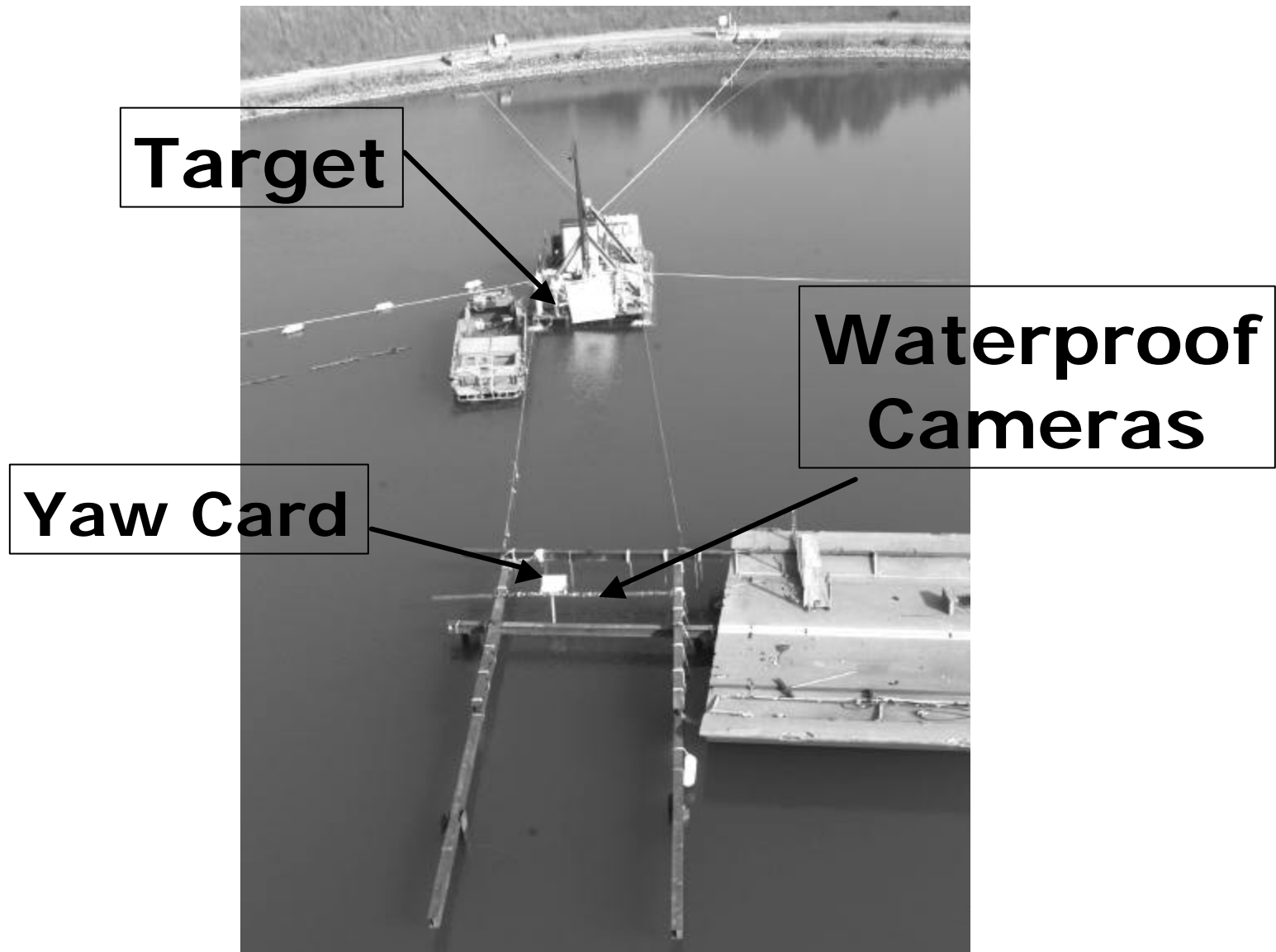
# Hydroballistic Test Peculiarities

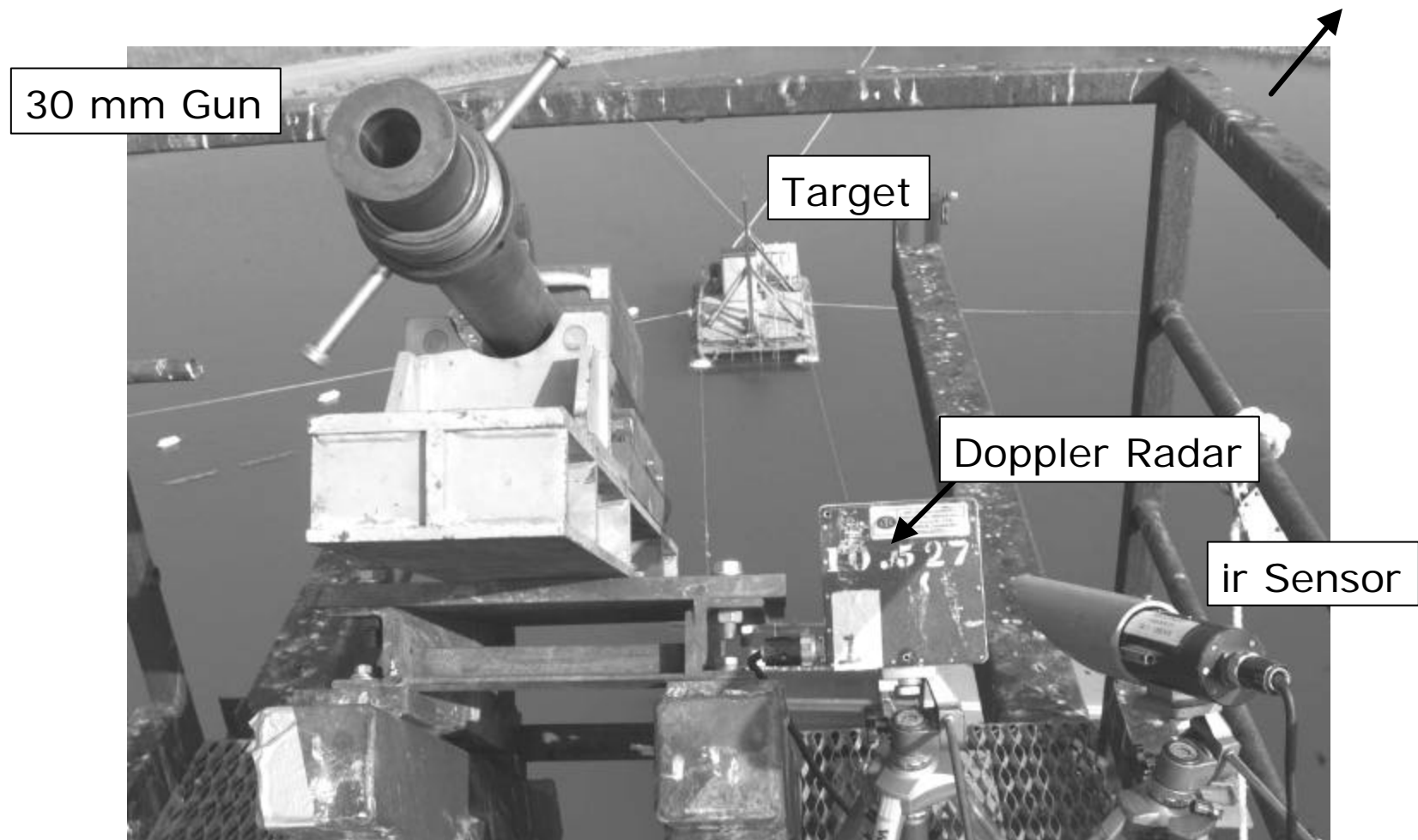
- Target “Sighting”
  - Land Based Surveying + Diligent Positioning
- Test Limitations
  - Limited Air Flight; Limited Water Depth
  - Underwater Cameras & Clarity Changes
  - Difficult To Measure Velocity
- Compounded Safety Considerations
  - Gun On Tower & Target In Water



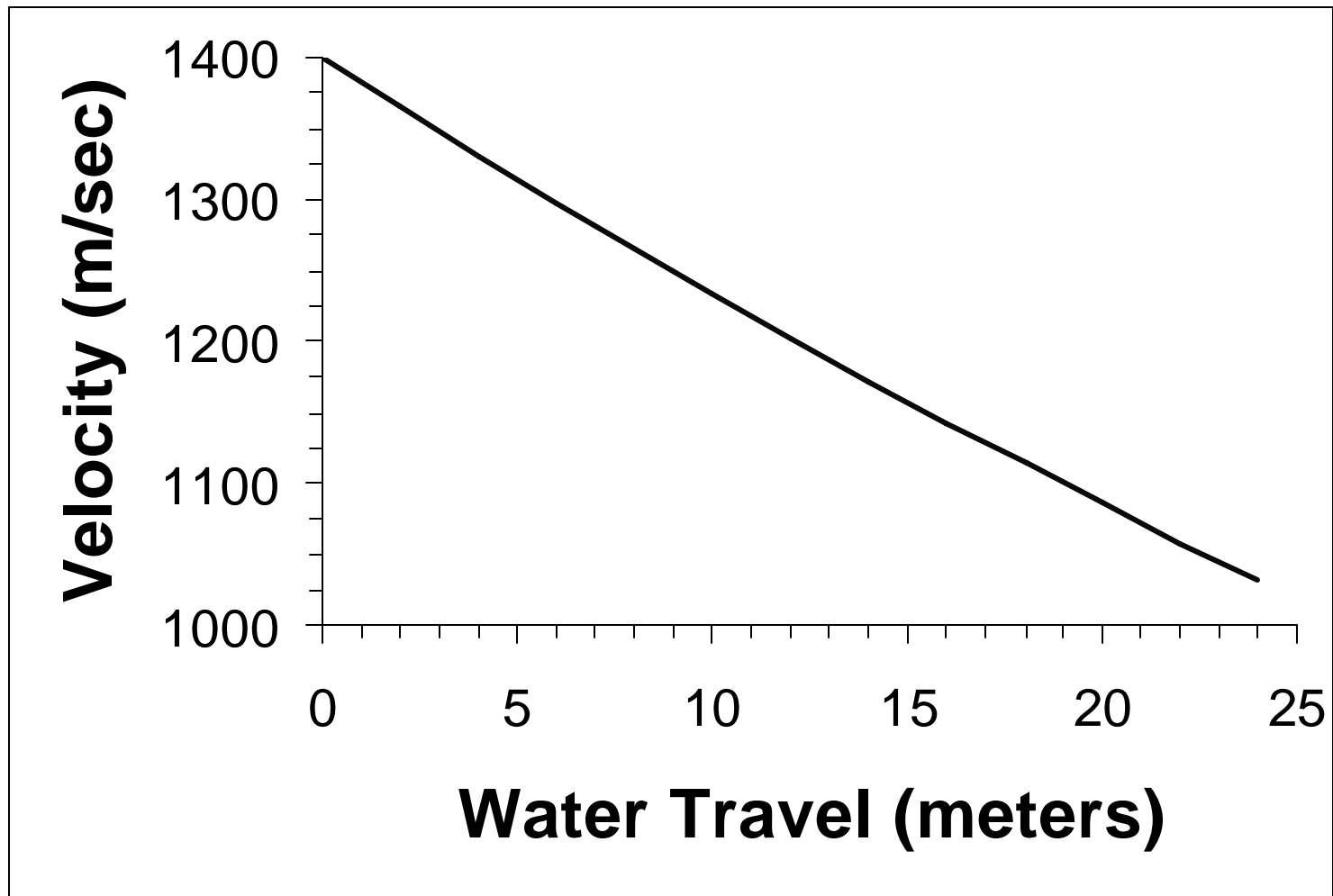


**Briar Point Test Site**

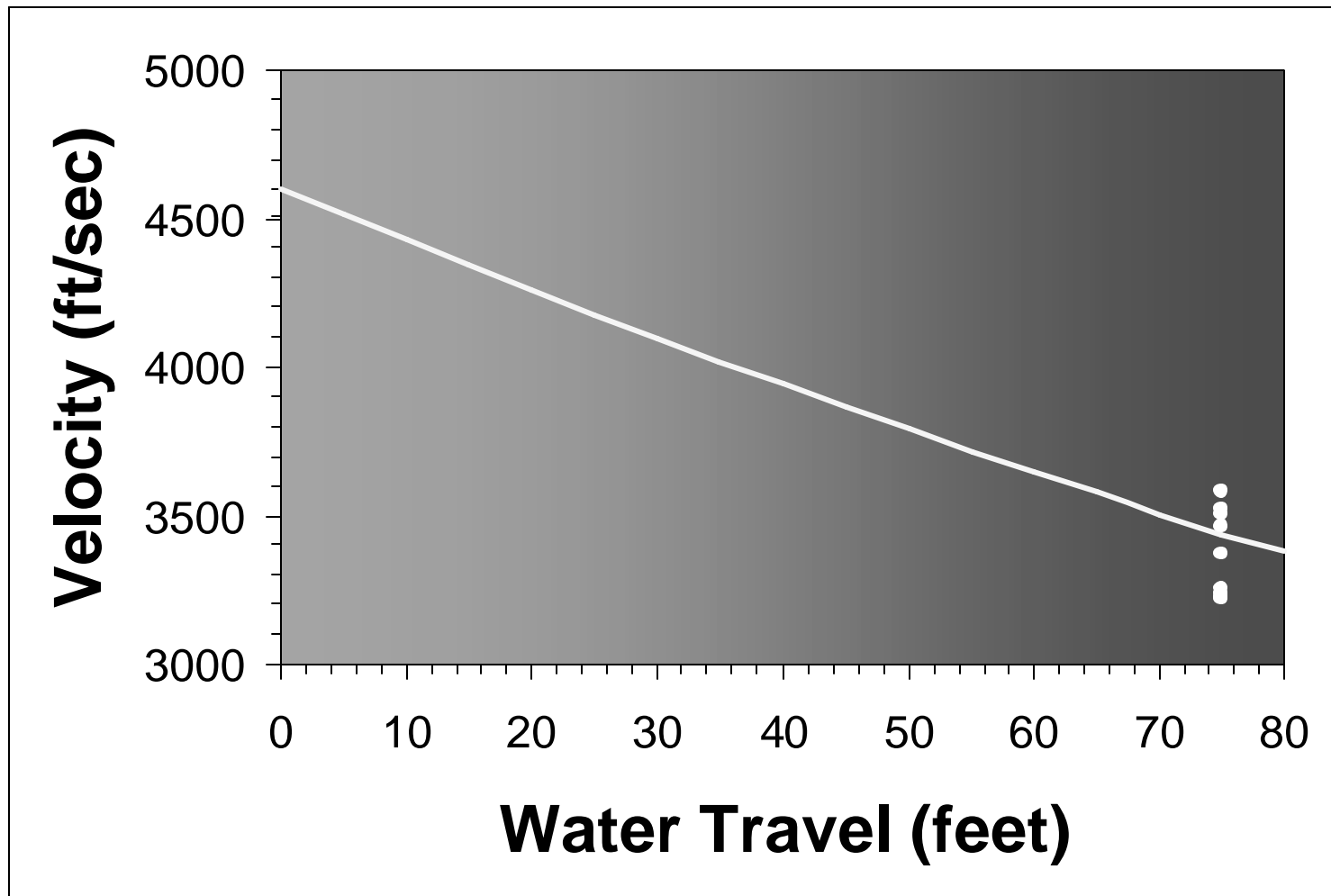


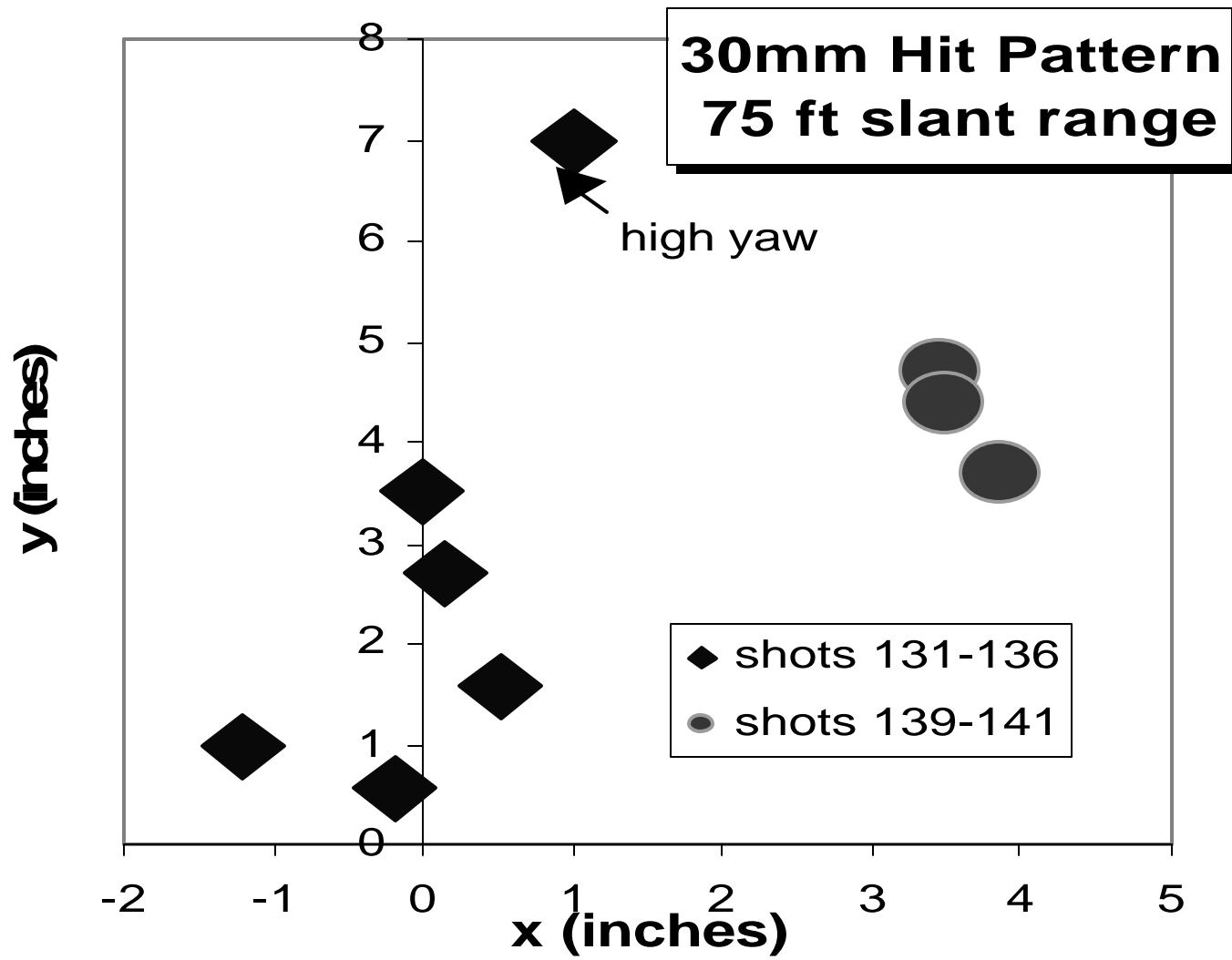


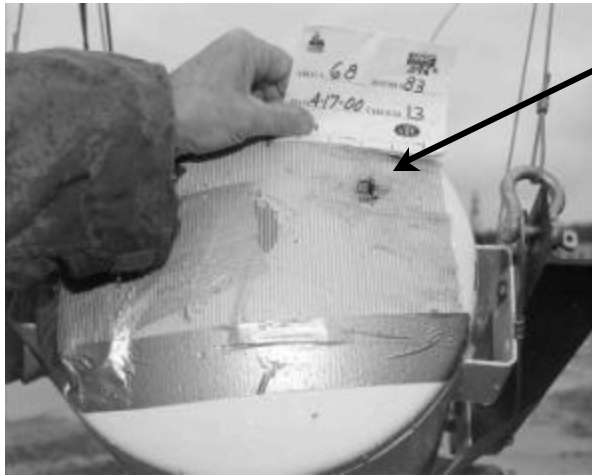
## 30mm MK 258 Hydro Performance



# 30mm MK 258 Hydro Performance







**Entrance hole**



30mm

1330 m/sec Water Entry

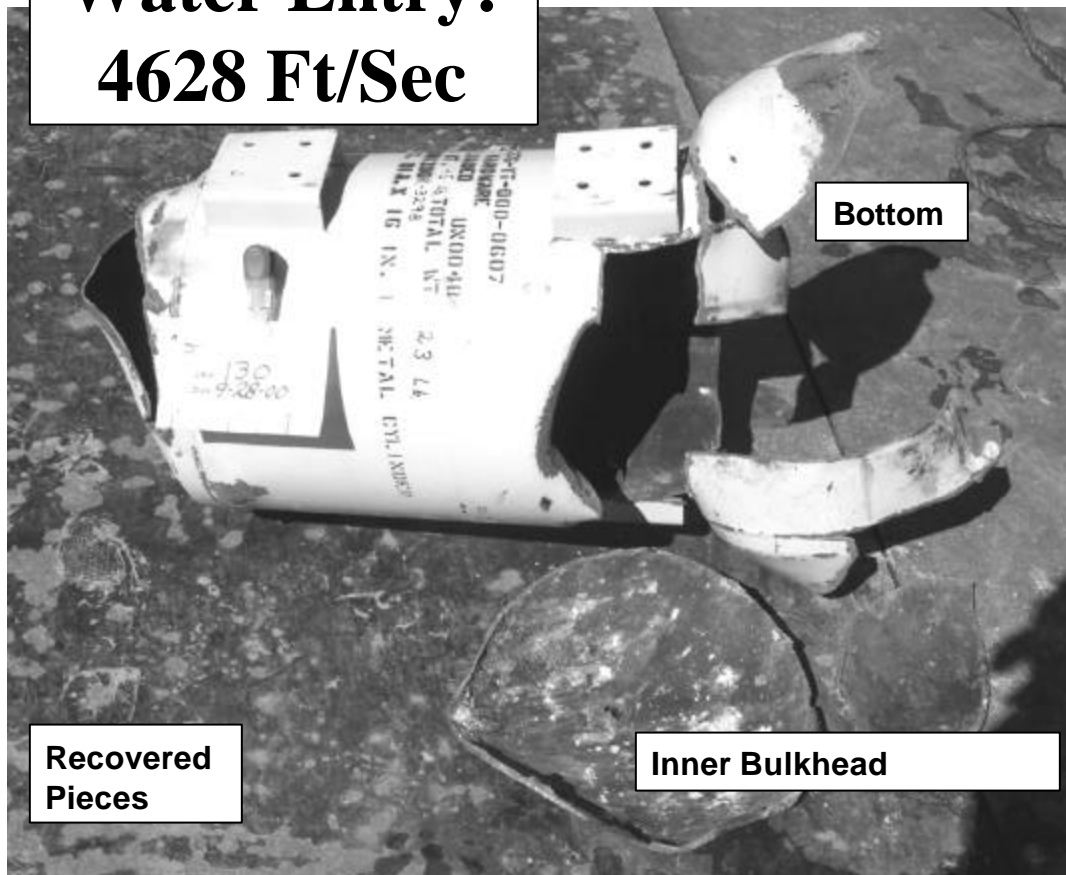
TARGET: Surrogate Mine

NEW: 45 lbs. TNT

Mooring Depth: 25 feet

**30mm  
20 Feet Deep**

**Water Entry:  
4628 Ft/Sec**





## **Other Aberdeen Test Results & Observations**

- Seventy 30mm Rounds Fired
  - Very Consistent Drag
- Underwater Dispersion
  - 0.70 To 1.4 Milliradians ( $1\sigma$  Radius)
- Demonstrated 5-Round Bursts Into Water
- Long-Rods Are Robust Hydroballistic Designs
  - Nose Material
  - Spin/Yaw
- Established Lethal Depth Capability

# Summary



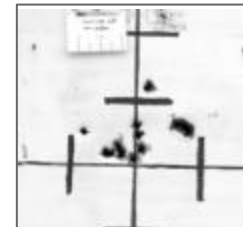
**Water Entry  
> 4600 Ft/sec**



**Improved  
Projectile  
Designs**



**Accurate Target Hits from  
75' Slant Range**



**Destruction of  
Surrogate Target**

***Shot 130***

***September 28, 2000  
Aberdeen Test Center***